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Determining Inertial Orientation of a Spinning Body With Body-Fixed Sensors

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Abstract

A methodology for determining absolute inertial angular orientation of a spinning body via independent angular measurements from two arbitrary body-fixed sensor systems is demonstrated. A particular application is denoted that uses U.S. Army Research Laboratory solar likeness indicating transducers and magneto-resistive sensors that provide body-fixed, independent angular measurements with regard to their respective local fields. Knowledge of the local field orientations and a coordinate transformation provides the inertial orientation angles, commonly called ψ and θ, which are useful for evaluating and developing advanced flight bodies and as a navigational aid for brilliant munitions. The combination of a dual field sensor system and the orientation determination methodology is called POINTER (Projectile Orientation In Navigation TERms). Typical sensor data and reduction processes are reviewed for a spinning body containing optical and magnetic sensors, and alternate field measurements are discussed.

ACKNOWLEDGMENTS

Mr. Brad Davis has been the lead engineer for the magnetic sensor experiments performed at the Weapons and Materials Research Directorate of the U.S. Army Research Laboratory. His efforts have greatly aided the authors in their appreciation of the potential of magnetic sensors. He is an integral part of the team pursuing engineering development of the MAGSONDE (MAGnetic SONDE).

The authors appreciate that the advances in body-fixed sensor use, which we believe MAGSONDE and POINTER represent, are only made possible by our augmenting previous efforts. Newton's famous statement in a letter to Robert Hooke comes to mind, "If I have seen farther, it is by standing upon the shoulders of giants." The bibliography, which is an attempt to recognize these predecessors, is far from exhaustive but will hopefully allow interested readers to further pursue related topics.

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Contents

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DETERMINING INERTIAL ORIENTATION OF A SPINNING BODY WITH BODY-FIXED SENSORS

1. Introduction

During development of and diagnostic experiments with military munitions and weapons systems, a significant need exists for projectile aerodynamic characterization, evaluation of guidance and maneuver systems, and measures of truth for inertial measurement units (IMUs). Accurate measurement of projectile motion via body-fixed sensors can contribute significantly toward the development of projectiles, rockets, and weapons systems and to the diagnosis of failures in existing systems. Ground-based instrumentation systems can provide such measurements but are generally used for only limited portions of a projectile flight for reasons of both expense and practicability in application. On-board instrumentation would seem a logical candidate for obtaining data throughout a flight, except for current expense and reusability. Additionally, a host of packaging and survivability issues is associated with the use of such systems in military applications. One such difficulty arises from g-loads exerted during impulsive launch and continuous free-flight roll. Traditional sensors, signal conditioning, acquisition, and telemetry devices that survive this mechanical loading have had a significant impact on a wide range of military systems, and therefore, similar qualification of state-of-the-art components, packaging, and processing schemes could lead to extremely reliable built-in measurement systems.

It is the primary objective of this report to describe a device and a simple, robust methodology wherein an on-board, multi-sensor system solution that employs optical sensors and magnetometers completely determines the orientation of a principal rotation axis of a spinning body with respect to a convenient navigational system. This device is called POINTER (Projectile Orientation In Navigational TERms). The continuous in-flight angular orientation histories obtained with POINTER can be used for projectile aerodynamic characterization and for investigation and evaluation of guidance and maneuver systems. POINTER will also provide a truth measure for the investigation and evaluation of other pointing angle measurement systems, such as rate-integrating inertial systems. The determination of the navigational pointing angle is important for the effectiveness of guidance and terminal seeking systems and advanced video imaging systems for target location. The POINTER orientation algorithm can be implemented within the device via electronics and signal processing to generate real-time navigational orientation or during post-flight processing of stored or telemetered data.

Many research and tactical applications of POINTER or some of its components are possible. POINTER can be generalized to include sensed alignments for any multi-field environment such as gravity or radio frequency (RF) fields. Conversely, if the navigational orientation is known, a magnetic field orientation can be defined. In addition, the mapping of deep space magnetic fields would be possible with multiple stars as light sources.

2. Generalized Multi-Field Orientation

The principal axis of rotation of a three-dimensional (3-D) freely flying solid body can be defined by a coordinate system that employs three variables denoting location and two variables defining angular orientation. The derivative of the location with respect to time is commonly referred to as the velocity vector, $\bar{V}$. The principal axis of rotation of a spinning body is often not co-linear with the velocity vector. In this case, orientation via a time history and derivatives of location variables does not provide an accurate determination of the navigational pointing angle. For a symmetrical, spinning body, the navigational pointing vector, $\bar{P}$, is coincident with the principal axis of rotation, commonly called the "spin axis." The rotation rate of the body about this axis is commonly called the "spin rate." The navigational variables ψ and θ are used to denote the two angular variables required to orient the body's principal axis of rotation within the navigational system. Measurement of the included angle between the axis of rotation and each field, knowledge of the field orientations, and favorable orientations of the fields with respect to the axis of rotation are required. Finally, a tabular pointing angle time history can be generated for this navigational coordinate system.

The generalized field transformation can be exemplified by combining the coordinate system with two representative field vectors of known orientation, $\bar{F}_1$, and $\bar{F}_2$, to yield the angle definitions shown in Figure 1.

Let the unit vectors $\bar{P}$, $\bar{F}_1$, and $\bar{F}_2$ along $\vec{P}$, $\vec{F}_1$, and $\vec{F}_2$ be defined within the (X, Y, Z) system as

$$
\begin{aligned}
\bar{P} &= (P_X, P_Y, P_Z) \\
\bar{F}_1 &= (F_{1_X}, F_{1_Y}, F_{1_Z}) \\
\bar{F}_2 &= (F_{2_X}, F_{2_Y}, F_{2_Z})
\end{aligned}
\tag{1}
$$

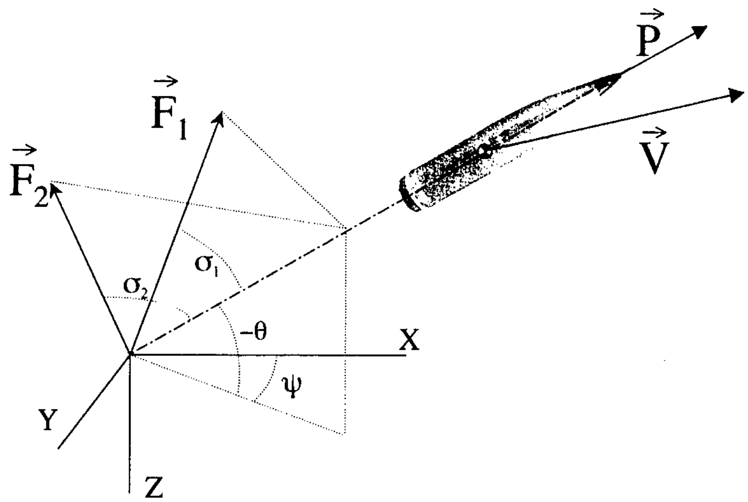


Figure 1. A Spinning Body Within a Convenient Navigational Coordinate System.

The components of $\bar{P}$ are obtained from the simultaneous solution of the system:

$$\begin{aligned} \bar{P} \cdot \bar{F}_1 &= \cos(\sigma_1) \\ \bar{P} \cdot \bar{F}_2 &= \cos(\sigma_2) \\ |\bar{P}| &= 1 \end{aligned} \tag{2}$$

in which $\bar{F}_1$, $\bar{F}_2$, σ_1, σ_2 are known, estimated, or measured. The pointing angles are then given by

$$\theta = \tan^{-1}\left(\frac{P_Z}{\sqrt{P_X{}^2 + P_y{}^2}}\right) \qquad \varphi = \tan^{-1}\left(\frac{P_Y}{P_X}\right) \tag{3}$$

The methodology yields two possible diametrically opposed pointing angle solutions. Knowledge of the initial navigational orientation resolves this trivial ambiguity. Furthermore, the unique solution can be maintained as long as vectors $\bar{P}$, $\bar{F}_1$, and $\bar{F}_2$ are not coplanar. It is a certainty that combining the angular measurements with respect to the fields requires restraint in application in order to preserve an accurate and unique solution. One can avoid numerical difficulties arising from small denominators in Equation 3 by choosing a favorable coordinate system.

3. Pointer

POINTER can be described as a hybrid device encompassing body-fixed sensors to uniquely define the navigational pointing angle of a spinning body. One particular example of POINTER is comprised of a number of high-g hardened optical sensors and magnetometers contained within a fuze volume suitable for gun-launched projectiles. The optical sensors are in a configuration consistent with SOLARSONDE to sense the solar field while the magnetometers are in a configuration consistent with MAGSONDE (MAGnetic SONDE) to sense the earth's magnetic field.

The ability of POINTER to determine a body's orientation in an earth-fixed navigational system rests on that body spinning within a dual field system, when the individual fields are distinct and have knowable orientations with respect to the earth. Measurement systems capable of attitude determination with respect to a single field have been successfully employed for many years in projectile testing, but the orientation within the navigational system is not unique for most cases.

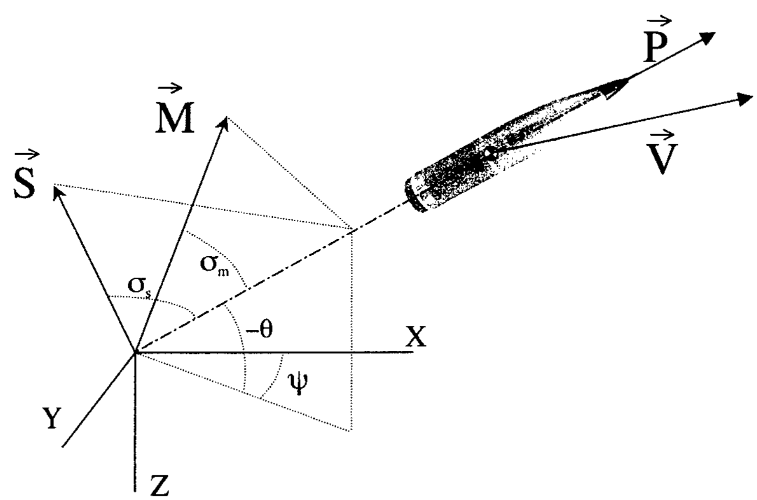


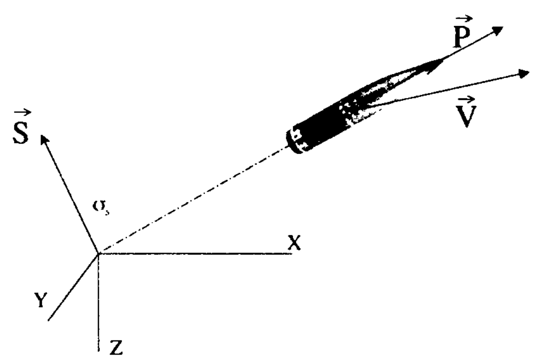
Figure 2. A Spinning Body Within Solar and Magnetic Fields Suitable for POINTER.

The accuracy and resolution of POINTER's navigational angle solution depend on the resolutions of the angular measurements with respect to the two fields and on the accuracy of the knowledge of the field orientations. Given that (a) the angle of the projectile with respect to each of the fields can be estimated to within 0.1 degree, (b) the orientations of the two fields are favorable, and (c) those field orientations can be determined to within 0.25 degree, POINTER can provide the navigational pointing angle to within 0.5 degree. Given a stationary magnetic

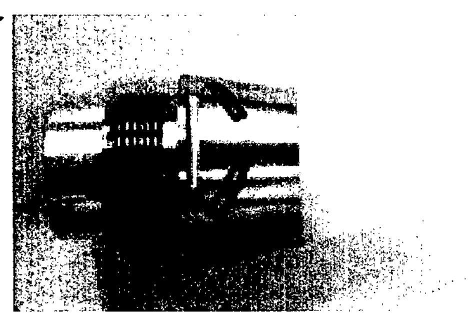
field and a solar field that varies significantly during the day, a measurement can be generated for most scenarios at some time during a day.

4. SOLARSONDE

Restricted slit silicon solar cells have been used at the Weapons and Materials Research Directorate[1] of the U.S. Army Research Laboratory (ARL) since the early 1970's to indicate solar attitude and roll rate of projectiles. These cells have been recently used in many projectile and missile programs for in-flight measurements of the solar aspect angle, which is defined as the angle between a spinning projectile's axis of rotation and the solar vector (see Figure 3a). However, determination of the angle between the spin axis and the solar vector does not uniquely specify the orientation of the spin axis within the navigational system. Figure 3b depicts installed sensors on a fuze body.



a. The angle between solar vector and spin axis



b. Optical sensors installed within a fuze volume.

Figure 3. SOLARSONDE: Solar Field Geometry and Exemplary Sensor Installation.

An optical sensor installed on a body at a known orientation and circumferential location embodies a device called a SOLARSONDE ("to sense the sun"), more commonly called a "yawsonde". Configurations that employ multiple sensors can be used to determine the solar aspect attitude of spinning, freely flying vehicles with respect to any parallel light source. A configuration of multiple sensors includes sensor(s) deliberately misaligned with the roll axis of the spinning body. SOLARSONDEs are routinely calibrated on an optical bench that contains a parallel light source and a 2-degree-of-freedom rotary table to determine the sensor installation parameters.

[1]formerly the Ballistic Research Laboratory

The optical sensor currently used as an indicator of solar field alignments was developed at ARL.[2] The common name for the current version of the sensor is a solar likeness indicating transducer (SLIT). Figure 4 exhibits an exploded assembly view of the sensor cell sides, sensor base, sensor, reflecting surfaces, obstructing pillar, and assembly pins. The sensor is compact, lightweight, and requires no power. The sensor housing includes obstructing geometry that restricts the amount of sunlight that enters and impinges upon the photoelectric cell. The restriction of light properly maintains a constant surface area of sensor illumination over a nearly theoretical half-plane of light acceptance. Thus, the device produces a significant output when it is aligned with the solar field and no output when it is misaligned.

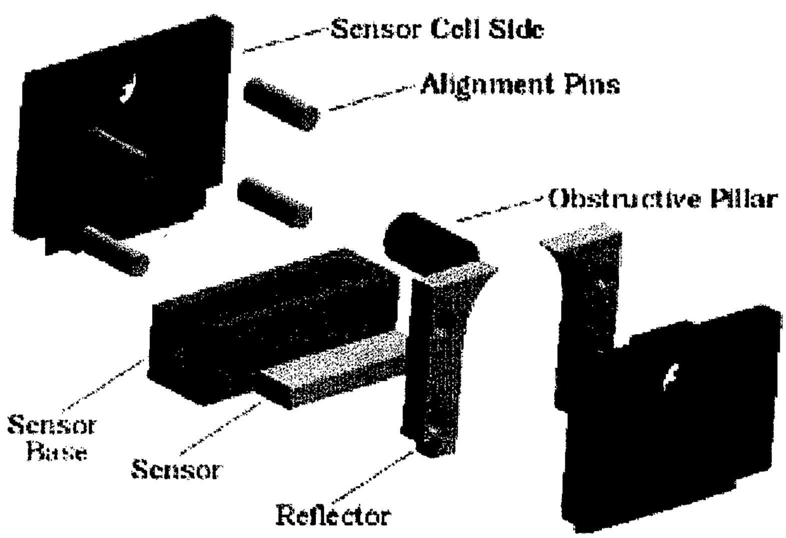


Figure 4. A Solar Likeness Indicating Transducer (SLIT).

Figure 5 shows a trivial period measurement that can provide a solar roll rate estimate for a projectile equipped with six sensors. Also depicted is the experimental measure of the solar aspect angle as derived from the phase relationship between sensor occurrences. Figure 5b portrays actual experimental flight data measurements of the solar aspect angle. The solar aspect angle can be further correlated to the calibration roll position data, and the accumulated roll history and related derivatives (roll rate and roll acceleration) can be generated with greater accuracy than can be achieved from the period measurement. Typical resolution is greater than 0.1 degree for solar aspect angle and 0.05 degree for solar roll position.

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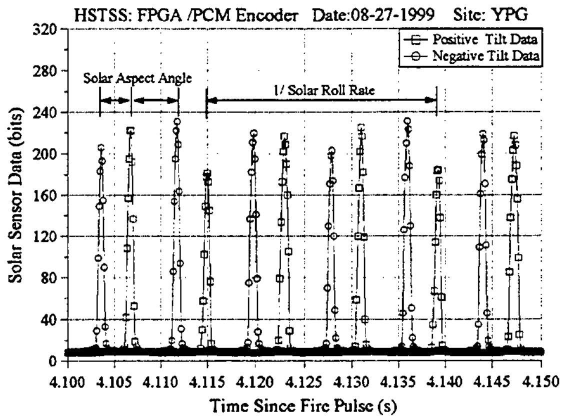
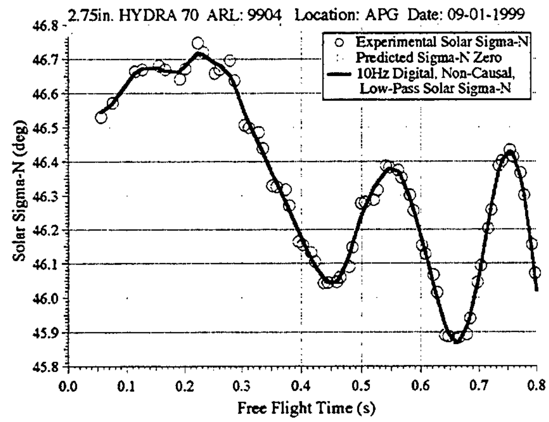
[2]U.S. patent number 5,909,275, entitled "G-Hardened Optical Alignment Sensor," was issued in June 1999 to D.J. Hepner and M.S.L. Hollis.



a. A consecutive series of sensor alignments.



b. Complement of the angle between the body and the sun.

Figure 5. Example of SOLARSONDE Sensor Excitations and Aspect Angle History Derived From Those Pulses.

5. MAGSONDE

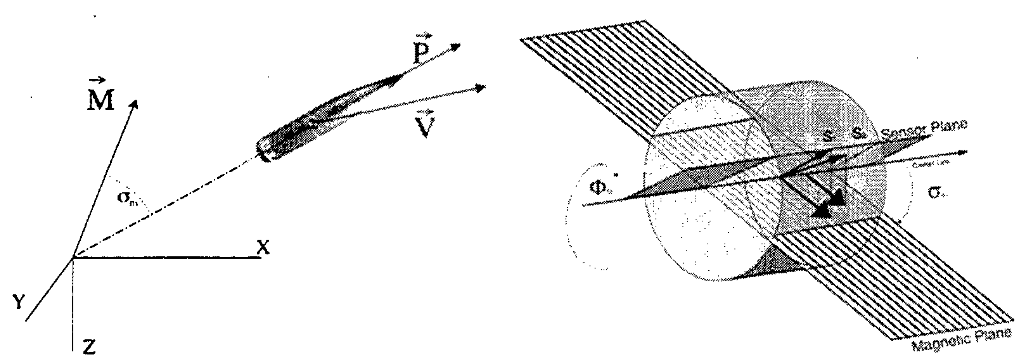
Another familiar measurable earth-fixed field is the magnetic field. Recent advances in magnetic sensor technologies have resulted in devices small enough, rugged enough, and sensitive enough to be usable on rapidly spinning bodies subjected to high-g forces. A developmental effort is patent pending for a measurement system called MAGSONDE, which uses such devices.[3] MAGSONDE employs fixed magnetic sensor(s) on a rotating body for the estimation of that body's orientation with respect to a stationary magnetic field. MAGSONDE is comprised of both an apparatus and a methodology that use sensor phase measurements to determine orientation. A MAGSONDE application of particular interest to the Army is measurement of in-flight angular orientation of spinning projectiles with respect to the earth's magnetic field.

Although devices responsive to the earth's magnetic field have long been used for heading estimation, MAGSONDE is a new and unique technology. It differs from all other known systems that give orientations with respect to a magnetic field in that those systems use one or more of four basic measurement types to determine orientations: 1) field strength along a sensor axis, 2) relative field strength along multiple sensor axes, 3) rate of change of field strength along a sensor axis, 4) relative rates of change along multiple sensor axes. In every case,

[3] by T.E. Harkins, D.J. Hepner, and B.S. Davis, all of ARL.

the angles are derived from measurements of magnetic field component along a sensor axis and require prior knowledge of the field and/or accurate sensitivity calibration. MAGSONDE only requires the magnetic sensor(s) to be used in identifying the times when the sensor axis is orthogonal to the ambient magnetic field. In this case, the angular estimates are premised on the detection of the absence of a magnetic field component along the sensor axis. At these zero crossings, MAGSONDE derives angular orientation from relative phase information in the sensor output. Thus, MAGSONDE is amplitude independent. This feature is important for several reasons: 1) No knowledge of the field strength is required, 2) manufacturing tolerances that affect sensitivity have no impact on orientation determination, and 3) only scalar arithmetical operations are required for the derived angular measurements.

Magnetic field strength along a sensor axis is a function of the total magnetic field intensity, the orientation of the body's axis of rotation, the body's magnetic roll angle, and the geometry of the sensor installation. Figure 6 defines the variables describing projectile orientation within a magnetic field and displays the orientation and excitation of two body-fixed magnetometers within that field. The magnetic plane is defined by the body's axis of rotation and a magnetic field vector. The sensor plane is defined by the body's axis of rotation and a sensor's sensitive axis. The angle between the magnetometer sensitive axis and the body's axis of rotation is defined as lambda (λ). The application of two sensors with distinct and non-supplementary λ_1 and λ_2 uniquely determines σ_M, the angle between the magnetic field and the axis of rotation. Knowledge of σ_M and calibration data yields a tabulation of roll angles between the magnetic plane for each sensor at the zero-output occurrence. Further, the magnetic roll angle (ϕ_M) is then the total accumulated rotation of the body. Related derivatives with respect to time can be generated to determine magnetic roll rate and magnetic roll acceleration.



a. Projectile orientation with respect to a magnetic field

b. Geometry of two magnetometers on a rolling body.

Figure 6. MAGSONDE Projectile and Sensor Geometries.

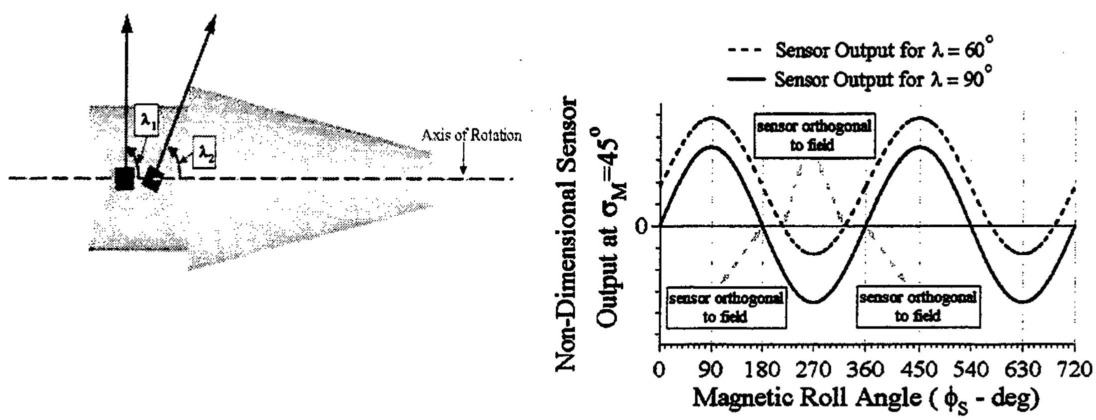
A fundamental MAGSONDE requirement is that projectile spin rotates the sensor(s) in a stationary magnetic field. The sensor(s) must have a nearly flat frequency response with minimal phase shift over a frequency range until it reaches at least two times the roll rate of the body to which it is fitted. A magnetometer suitable for a MAGSONDE must also have a direct current (DC) response characteristic to the magnetic field. For the epicyclical motion typical of spinning projectiles, the processing of the sensor data for MAGSONDE is straightforward when the spin rates are much greater than the precession and nutation rates. When this condition is not met, more advanced processing algorithms are employed with comparable results.

The MAGSONDE system makes only a single demand of its magnetic sensors, the identification of zero output. Thus, material sensitivity variations, field strength variations, and attenuating flight body materials will have no effect on MAGSONDE performance. Given existing materials responsive to the desired range of magnetic field strength, a sensing device with a favorable signal-to-noise ratio is readily achievable. However, units with built-in electronics must provide a stable scale factor (gain) and bias (offset) characteristics.

One can derive magnetic attitude by evaluating the output from a pair of sensors. For sensors situated with their sensitive axes coplanar with the projectile's spin axis and oriented at non-zero tilt angles ($\lambda_1 = 90^\circ$ and $\lambda_2 = 60^\circ$) from the spin axis, Figure 7 depicts the sensor installation within an artillery fuze and the resulting non-dimensional idealized DC sensor output throughout two magnetic roll periods when $\sigma_M = 45^\circ$. Because of tolerances in the manufacturing and installing of the various sensors, the actual orientations of the sensors on a flight body will differ from their designed values. After sensor installation, each MAGSONDE system will be calibrated with a magnetic field generator and a 2-degree-of-freedom rotary table. The flight body will be installed on a calibration table that allows angular orientation to be changed in both ϕ_M and σ_M. Magnetic roll positions at orthogonality versus σ_M will be tabulated. These data are used to determine the installed circumferential location and tilt angle of each magnetometer's sensitive axis.

The temporal sequence of zero crossings of these sensors is similar to a sequence of solar crossings obtained with a SLIT optical sensor. This methodology of magnetometer sensor data interpretation makes MAGSONDEs in many ways analogous to SOLARSONDEs. This is a conscious design decision that employs the data reduction and analysis capabilities developed during 30 years of SOLARSONDE use in gun- and tube-launched projectile flight tests. There are four important distinctions: outer surface access, launch window, bias sensitivity, and frequency response. The main disadvantages for a SOLARSONDE are the requirement for access to the exterior surface of a rotating body and the dependence on an unobscured solar line of sight. Given that an observable measurement is possible, the internally mounted magnetic sensors of

a MAGSONDE have the advantage of an unchanging magnetic launch window suitable for day/night and all-weather conditions. For some projectile orientations, the converse argument for the SOLARSONDE is that, as time passes, the daily variation in the solar vector will always ensure an observable solar angle measurement while the unchanging magnetic field may not ever yield a measurement. The current SOLARSONDE has no susceptibility to bias or frequency response that can drastically change the derived angular measurement from a MAGSONDE. Thus, the MAGSONDE has a stringent signal conditioning and instrumentation calibration requirement.



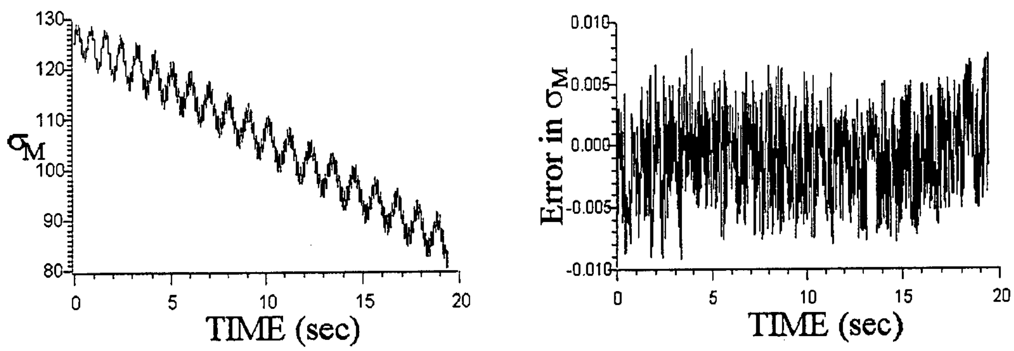
a. Fuze-configured two-sensor MAGSONDE. b. Idealized sensor output.

Figure 7. Representative MAGSONDE Sensor Installation and Signals.

Potential applications for MAGSONDE output include determination of angular motion histories of experimental, developmental, and tactical projectiles. The resulting angle data can be used with diagnostic tools for projectile aeroballistic characterization, determination of maneuver authority for guided munitions, and weapon-projectile-payload interaction analysis. The sensor data can also provide a relative roll orientation and roll rate reference for the calibration of on-board data sources such as accelerometers and angular rate sensors. Finally, the combination of magnetic sensors and on-board processing data potentially provides navigational assistance for "jammed" global positioning system (GPS) fitted munitions.

Using a 6-degree-of-freedom trajectory code, the authors simulated a flight of the exemplary MAGSONDE configuration on board an M483A1 artillery projectile. For the shot line and magnetic field orientation at ARL's transonic range, a σ_M history throughout the trajectory was generated for idealized 64-bit sensors via the standard MAGSONDE algorithm. These results represent the theoretical boundary on accuracy of that algorithm when applied to this trajectory.

Although experimental results are not yet analyzed, it is expected that an accuracy of 0.1° or better in estimates of σ_M will be achievable.



a. MAGSONDE estimate of angle between spin axis and magnetic field, σ_M

b. Error in MAGSONDE estimate of σ_M

Figure 8. MAGSONDE Orientation Estimates and Errors for Simulated Idealized System.

6. Launch Window

The suitability of this particular POINTER system for a given flight depends on the range of possible solar and magnetic headings during that flight. Given known and sufficiently distinct solar and magnetic field orientations at the flight location and an estimate of the anticipated trajectory, possible sensor configurations and lines of fire that result in good geometry can be determined.

Although the orientation of the earth's magnetic field varies slowly over both location and time, these variations are regular and known or measurable. Moreover, the variations over the length and duration of a projectile trajectory are typically negligible, except for local anomalies. Thus, given knowledge of the flight location, the magnetic field near the earth's surface can be obtained from geodetic survey data, computer models, or direct measurement. Simulated trajectory data are then used to estimate the nominal anticipated magnetic heading angle history. In some cases, it will be true that for a portion of the trajectory, the body's attitude with respect to the magnetic field will be within the MAGSONDE measurement capability some times and outside that capability at other times.

The orientation of the solar vector for any location can be measured or estimated from an algorithm with a single, time-stamped solar observation and an estimate

for the seasonal variation in tilt angle and rotation rate of the earth. An additional requirement for a SOLARSONDE measurement is an unobstructed solar line of sight. The diurnal variation in solar vector orientation is advantageous to the POINTER launch window since field orientations can be optimized to ensure a highly accurate measurement, regardless of the shot line.

7. Pointer Flight Experimental Design

For military applications, the sensor(s) must be small and rugged and must consume very little power. Devices of this nature are currently being developed by the Defense Advanced Research Program Agency (DARPA). Investigation of their applicability to MAGSONDE is a main consideration for the development, experimentation, and final vendor selection for particular military applications. While the sensor selection is significant, a listing and evaluation of candidate devices is beyond the scope of this report and would needlessly date the otherwise time-independent content. In general, sensors and instrumentation systems are routinely qualified to 40,000 gs to verify survivability and operation.

The Advanced Munitions Concept Branch, Weapons and Materials Research Directorate, of the U.S. Army Research Laboratory (ARL) can produce a miniature on-board data acquisition system within a North Atlantic Treaty Organization (NATO)-compatible fuze volume fitted with ARL patented optical sensors, magnetic sensors, a micro-electro-mechanical systems (MEMS) accelerometer, a lithium manganese dioxide ($LiMnO_2$) primary battery, and a commercially available high-g transmitter-antenna package. The current diagnostic fuze design has an available internal volume of 8 in^3. The primary battery, connector, and the transmitter package account for almost 75% of the volume, with 1.56 in^3 remaining for sensors and instrumentation payloads.

Current practices of sensor data collection methods include telemetry transmission to a ground station. The ultimate objective is to acquire a temporal history of critical data points within the sensor time history from which to derive the individual angular measurements of σ_M and σ_S. These angles are then used to determine the navigational orientation of the rotation axis, as previously described. All available data will be collected and archived and can be processed in the field environment to provide feedback during an experiment and to enhance the flexibility of the study requirements. Advanced reduction techniques can be substituted when appropriate (including but not limited to) compensation for rapid changes in either aspect angle or spin rate is absent.

The first implementation of POINTER used solar and magnetic sensors that were installed in a NATO-compatible fuze volume suitable for use on a spinning

projectile. In addition, the optical and magnetic sensor signals were combined on board to reduce the number of signal channels required. An ancillary benefit of this on-board mixing is that phase and amplitude errors introduced by multi-channel telemetry are reduced. Figure 9 exhibits combined data from a spinning artillery shell fired at Yuma Proving Ground, Arizona. The optical and magnetic data are easily separable.

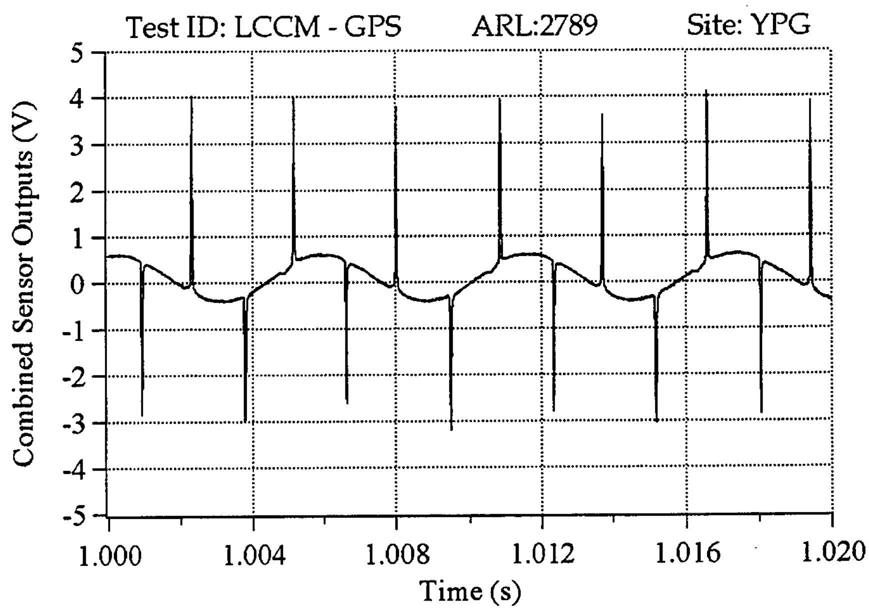
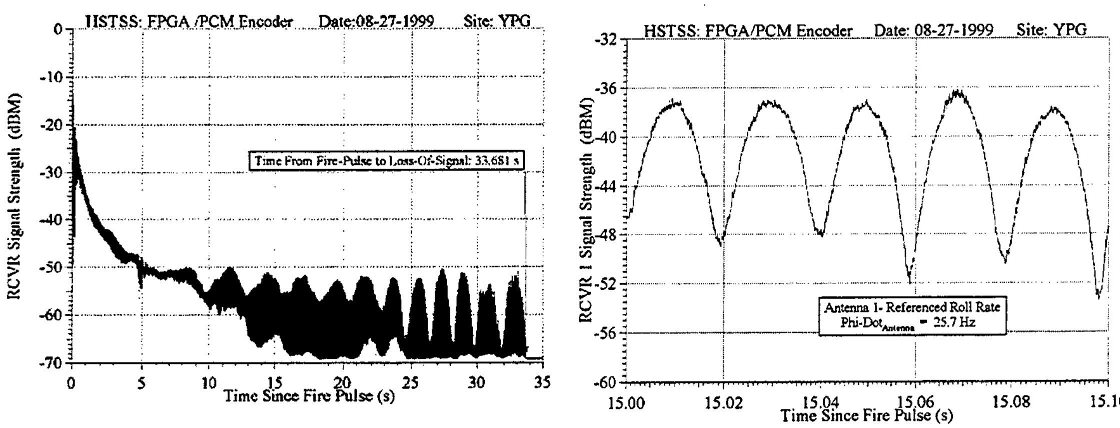


Figure 9. Experimental Flight Data of Mixed Optical Sensor and Magnetometer Onto a Single Data Channel.

8. Alternate Fields

Several examples of fields that can be distinguished with ease are gravity, sunlight, and the earth's magnetic field. Gravity can be easily sensed on a rotating body fixed to the earth via accelerometers. A body in free flight, however, cannot sense the earth's gravitational field since the force acts upon both the body and the sensing element equally. For a body in free flight, the earth's magnetic field and sunlight offer two convenient reference fields whose orientation can be defined with sufficient resolution to provide an inertial angular orientation solution. Other examples of reference fields that can be determined and sensed include telemetry radio frequency (RF) fields, GPS RF fields, millimeter wave radar, and passive radiometric fields. The sole requirement of the field sensing is to provide a response of some nature that will indicate orientation with respect to that field.

For each projectile fitted with an RF transmitter, data related to the received signal strength, automatic gain control (AGC), can be acquired. Calibrated AGC data are a measure of the signal strength at the receiver input, which provide a quantitative measure of the telemetry link performance. The AGC data can serve as an independent metric of data confidence and can be used as weighting values in data analysis algorithms. The characteristic decay of signal strength is largely a function of distance squared, although transmission and reception antenna patterns also play a large role in measured signal strength. Finally, multi-path effects can cause cancellation because of out-of-phase wave arrival at the receiving antenna. Figure 10 shows representative received signal strength from a body-fixed bi-directional radiator antenna in S-band. Upon close inspection of Figure 10b, a repeating pattern of attenuation is evident as the two nulls of the projectile-borne antenna are detectable with respect to the receiving antenna. Thus, the body roll rate is earth referenced by a rotating body-fixed RF field. In addition, advanced applications could include spinning fields that can be generated by a rapidly rotating body and can be sensed by stationary ground-based measurement systems.



a. Signal strength data from a projectile-borne transmitter

b. Body roll as indicated by transmitted antenna nulls.

Figure 10. Variations in Sensor Response can Provide Projectile Orientation Information.

9. Conclusions

POINTER is a device and a methodology wherein a multiple field environment is used to determine the orientation of a spinning body within a convenient navigational coordinate system. An example is described that contains a constellation of optical and magnetic sensors. Methodologies are developed for data processing to generate angular orientation in real time or post flight. Potential applications for POINTER data include determination of angular motion histories of experimental, developmental, and tactical projectiles. The

resulting angle data can be used with diagnostic tools for projectile aeroballistic characterization, determination of maneuver authority for guided munitions, and weapon-projectile-payload interaction analysis. The processed data can also provide a relative roll orientation and roll rate reference for calibrating on-board data sources such as accelerometers and angular rate sensors. Finally, the combination of magnetic sensors and on-board processing data potentially provides navigational assistance for "jammed" GPS-fitted munitions.

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13. ABSTRACT *(Maximum 200 words)*

A methodology for determining absolute inertial angular orientation of a spinning body via independent angular measurements from two arbitrary body-fixed sensor systems is demonstrated. A particular application is denoted that uses Army Research Laboratory solar likeness indicating transducers and magneto-resistive sensors that provide body-fixed, independent angular measurements with regard to their respective local fields. Knowledge of the local field orientations and a coordinate transformation provides the inertial orientation angles, commonly called y and q, which are useful for evaluating and developing advanced flight bodies and as a navigational aid for brilliant munitions. The combination of a dual field sensor system and the orientation determination methodology is called POINTER (Projectile Orientation In Navigation TERms). Typical sensor data and reduction processes are reviewed for a spinning body containing optical and magnetic sensors, and alternate field measurements are discussed.

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